Queen Charlotte Islands Stream Rehabilitation Studies
A Review of Potential Techniques

Land Management Report NUMBER 28

ISSN 0702-9861

September 1984

BC
Ministry of Forest

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Queen Charlotte Islands Stream Rehabilitation Studies A Review of Potential Techniques

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BC
Ministry of Forests

Canadian Cataloguing in Publication Data

Bustard, David R., 1950-
Queen Charlotte Islands stream rehabilitation studies

(Land management report, ISSN 0702-9861 ; no. 28)

Bibliography: p.
ISBN 0-7718-8463-X

1. Fish habitat improvement - British Columbia - Queen Charlotte Islands. 2. Stream conservation - British Columbia - Queen Charlotte Islands. 3. Mass-wasting - Environmental aspects - British Columbia - Queen Charlotte Islands. I. British Columbia. Ministry of Forests. II. Title. III. Series.

SH157.8.B87 1985 639.9'77'0971131 C85-092058-2

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Published by the
Information Services Branch
Ministry of Forests
1450 Government Street
Victoria, B.C.
V8W 3E7

Copies of this and other Ministry of Forests titles are available at a cost-recovery price from Queen's Printer Publications, Parliament Buildings, Victoria, B.C. V8V 4R6.

ABSTRACT

The potential techniques for the rehabilitation of small streams which have been degraded by mass wasting on the Queen Charlotte Islands are reviewed. Experience with possible rehabilitation techniques in other parts of the Pacific Northwest is summarized and suggestions on their applicability for Queen Charlotte Islands streams are made. It is stressed that stream rehabilitation is not an alternative to sound habitat protection. Stream rehabilitation should be considered only after an assessment of the factors actually limiting fish production is made. This report summarizes studies and literature results to the end of 1981.

ACKNOWLEDGEMENTS

The author would like to acknowledge the co-operation of various staff members of the B.C. Fish and Wildlife Branch, the Canadian Department of Fisheries and Oceans, and the International Pacific Salmon Commission for providing valuable background information on stream rehabilitation projects not documented in the literature. As well, various staff members of the U.S. Forest Service, the U.S. Bureau of Land Management, the Washington State Department of Fisheries, and the Washington State Department of Natural Resources provided valuable information. Dr. Jim Hall of Oregon State University kindly made available draft copies of a number of manuscript reports which were very helpful. Dionys deLeeuw, Pat Slaney, and Craig Wightman reviewed the final draft of the manuscript. The assistance of librarian Leigh-Ann Topfer of Envirocon Ltd. is gratefully acknowledged.

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INTRODUCTION

Forestry and fishing have traditionally dominated the economy of the Queen Charlotte Islands. During the last decade the forest industry has expanded and some operations have shifted to steep, less-stable terrain. As a result, an accelerated rate of mass wasting has occurred in steepland areas, and considerable attention has focused on the impact of this process on fish streams in the Queen Charlotte Islands. Fishery agencies have expressed continued concern that landslides caused by logging are degrading many small but productive salmonid streams.

In response to this situation, the Fish/Forestry Interaction Program (FFIP) was initiated to research the results of mass wasting on the fish and forest resources of the Queen Charlottes, and to develop strategies to minimize these impacts. One aspect of this applied research is the assessment of techniques for rehabilitating streams that have been damaged by landslides.

Considerable experience with stream rehabilitation has been acquired in eastern North America during the past 50 years. Although stream rehabilitation is relatively new to fishery biologists in the forested regions of the Pacific Northwest, a number of programs have been undertaken with varying degrees of success. To take advantage of previous experience, the first phase of the FFIP stream rehabilitation program has been to review past efforts in the Pacific Northwest.

This paper includes a review of the available literature and reports on some on-site examinations of stream rehabilitation techniques used in the Pacific Northwest. Comments are made on the applicability of these techniques to Queen Charlotte Islands streams that have been affected by mass wasting. The report summarizes studies and literature to the end of 1981.

THE STUDY AREA

The Queen Charlotte Islands consist of approximately 150 islands lying off the central coast of British Columbia (Fig. 1). Two major islands, Graham and Moresby, comprise most of the 9940 km^2 of land mass.

Nearly 200 streams contribute to salmon spawning escapements averaging more than 1 million fish annually (Canada Dep. Fisheries and Oceans 1978 and 1979). The predominant salmon species based on stream escapement counts since 1947 are as follows:

Species	% of escapement
Pink salmon (Oncorhynchus gorbuscha)	54
Chum salmon (Oncorhynchus keta)	35
Coho salmon (Oncorhynchus kisutch)	7
Sockeye salmon (Oncorhynchus nerka)	3
Chinook salmon (Oncorhynchus tshawytscha)	1

Coho salmon probably comprise a higher proportion of the escapement than indicated, but are difficult to enumerate effectively. Many streams of the Queen Charlotte Islands possess populations of steelhead trout (Salmo gairdneri), an increasingly rare and recreationally valuable fish. The steelhead catch per day on the Queen Charlotte Islands has consistently been the second highest of the seven regions in British Columbia (B.C. Fish and Wildlife Branch 1979-1980). Populations of cutthroat trout (Salmo clarki) and Dolly Varden char (Salvelinus malma) are also present in many streams.

Many streams on the Queen Charlotte Islands originate in steep headwater areas that have some low-gradient areas suitable for spawning salmonids often restricted to the lowest few kilometres. Coho and steelhead are typically distributed throughout the accessible length of streams, while pink and chum salmon generally concentrate in the lowest sections, which sometimes consist of only a few hundred metres of suitable spawning habitat.

Most small streams on the Queen Charlotte Islands are subject to highly variable discharges resulting from heavy rainfall and few headwater lakes to moderate flows. Although streamflow data only exist for two lake-headed systems, an 800-fold difference between low summer flows and peak winter freshets has been recorded. In streams without lakes, discharge extremes are undoubtedly greater, particularly on the west coast where rainfall averages over 400 cm annually.

FIGURE 1. Location of Queen Charlotte Islands.

BACKGROUND: POTENTIAL IMPACTS OF MASS WASTING ON THE STREAM ENVIRONMENT

Continuing studies on the Queen Charlotte Islands are assessing the results of mass wasting on the stream environment. Because these studies are in the early stages of development, results are not available. To provide some background as to why stream rehabilitation is being considered, and in what direction it may be best oriented, a discussion of potential impacts is appropriate. This discussion is preliminary and speculative, and relies on some field observations made in conjunction with the 1981 stream studies and on information derived from investigations elsewhere.

Mass wasting can be separated into two categories useful for discussing in-streams impacts: 1) debris torrents; and 2) all other mass movements such as debris slides, avalanches and flows, and slumps and earthflows as described by Swanston (1980).

Debris Torrents

Debris torrents have the most visible impact on streams in the Queen Charlottes. Although they generally occur in the steeper gradient intermittent channels and often terminate near the upper extent of anadromous fish habitat, some debris torrents do move through anadromous fish habitat (e.g. MacMillan Creek, Thurston Harbour Creek). The initial slurry of water and associated debris commonly entrains large quantities of additional material from the steambed and banks. As the torrent moves downstream, extensive areas of channel may be scoured to bedrock and a large matrix of debris and sediment is deposited at the base of the torrent. Velocities of debris torrents, estimated to be up to several tens of metres per second, are known only from a few spoken and written accounts (Swanston 1980). Although debris torrents pose significant hazards to anadromous fish habitat, they have received little study.

A torrent moving through a stream channel can result in massive shifting of the streambed material, crushing and displacing eggs, alevins, aquatic organisms, and juvenile fish. Aside from the immediate impacts of the event, probable long-term impacts of debris torrents include the following:

1. In-stream debris is redistributed following a debris torrent, and typically accumulates in the run-out zone of the torrent or high on the streambanks. Stable in-stream debris provides bed stability in stream channels (Swanson and Lienkaemper 1975). Pools formerly developed around accumulations of debris will be replaced by riffles, leading to a net increase in riffle areas and generally a loss in stream rearing capability (Bryant 1980). Lower juvenile coho standing crop has been shown to be strongly correlated with decreased pool volume (Nichelson and Hafele 1978). Debris destabilized by a torrent will continue to be mobile at high discharges and contribute to continued bed scouring and bank erosion problems.

2. Accumulations of debris at the lower end of a torrent may be up to 6 m high and are usually barriers to fish movement upstream. These debris accumulations can trap bedload material resulting in a deficiency of spawning gravels downstream (e.g. Showmar Creek).

3. Water temperatures during low summer flows may exceed 20°C due to an absence of vegetation along a torrented creek.

4. Coarse bed material may accumulate in a channel incapable of moving it. This aggradation of material results in a widened channel with fewer pools (Lisle 1981) and low summer flows may become entirely subsurface (e.g. Richardson Creek). Bed materials are most likely to accumulate in the downstream low gradient section of a stream, which generally has less ability to move introduced material.

5. A debris torrented stream may experience a subsequent input of silt from material stored in the channel and from scoured streambanks due to surface erosion and small-scale slumping and sloughing (Swanson et al. 1976).

6. A short-term and possible long-term reduction in the benthic fauna.

A number of studies have reviewed the detrimental impacts of sediments on the spawning and rearing environments of salmonids (Phillips 1971; Slaney et al. 1977; Bjornn et al. 1977; Cederholm and Salo 1979). Many streams affected by mass wasting on the Queen Charlottes are relatively steep, high-energy systems, and may be capable of moving the finer sediment materials through the system quite rapidly. Cederholm and Salo (1979) found that a stream system with a 2-4% gradient and a high maximum-minimum flow ratio (400-500:1) had the ability to flush sediments caused by landslides. However, a low gradient system (1-2%) characterized by heavy accumulations of large organic debris retained sediments in the spawning gravels for a much greater time. Experience at Carnation Creek has shown that the sand component is accumulating in the spawning gravels in the lower 2 km of the creek (Scrivener and Brownlee 1981).

Other Forms of Mass Movements

The impacts of other types of mass wasting occurring adjacent to a stream channel depend on the nature, volume, and rate that materials are introduced and the capability of a stream to move them through the system. Slumps and earthflows are for the most part slow moving, and provide a continuous long-term source of sediment to the channel. Debris avalanches and debris flows are rapid shallow mass movements that develop on steep hillsides and generally contribute 60% or more of their initial failure volume almost immediately to the channel (Swanston 1980).

Debris avalanches and flows into streams may result in channel alteration, a rapid increase in bed and suspended loads, siltation of gravels, and partial or complete blocking of the stream channel through debris jam formation. Studies on Maybeso Creek, Alaska, indicate that large floatable debris commonly destabilized existing natural accumulations of debris and eventually resulted in fewer debris accumulations (Bryant 1980).

In summary, debris torrents and other forms of mass wasting probably affect both the spawning and rearing capabilities of the stream system in a variety of ways. Aside from the event itself which may be catastrophic to the stream ecosystem, longer-term impacts can include a deterioration

in gravel quality and stability and a loss of access to spawning areas. A reduction in juvenile rearing habitat may result from a redistribution of large organic debris in the stream and from changes in the channel characteristics, which may lead to less pool habitat and greater subsurface flows - a critical factor during the late summer low-flow period.

REVIEW OF REHABILITATION TECHNIQUES

In its strictest sense, stream rehabilitation refers to repair of abused or deteriorated habitat to speed up natural recovery. Stream enhancement refers to the creation of a greater amount of suitable habitat than would occur naturally in a stream. In this report, discussions will incorporate some small enhancement schemes with stream rehabilitation, since the separation of the two is illogical in plans for the restoration of damaged habitat.

This review of rehabilitation studies benefited from availability of two recent extensive reviews of the literature and current field applications conducted by Hall and Baker (1982) in Oregon, and Reeves and Roelofs (1982) in northern California. As well, several reviews of techniques that can be used in the restoration of streams have been prepared in British Columbia (Parkinson and Slaney 1975; Canada Dep. Fish. and Oceans and B.C. Min. Environ. 1980).

The application of techniques suitable for use in stream rehabilitation is rapidly evolving in the Pacific Northwest, particularly in Oregon and California where there has been a shift in emphasis from artificial enhancement to restoration of in-stream structures designed to facilitate natural reproduction of wild stocks. As Hall and Baker (1982) point out, many projects have not been adequately documented, and those that have been often lack an adequate design to provide an accurate assessment of the outcome. Few unsuccessful projects are reported in the literature, and valuable lessons to be learned from these failures are usually not shared.

It is essential that a rehabilitation program not be initiated until factors limiting production in a given stream have been identified and evaluated. If salmonid production in a stream is limited by rearing, nothing is to be gained by enhancing spawning habitat.

For coho and steelhead, the availability of rearing habitat is usually the main factor influencing production, and habitat improvement efforts should be aimed at improving suitable rearing areas. It is important to recognize which phase of rearing is limiting. For example, Mason (1976) found that despite increasing the summer carrying capacity of coho in a small Vancouver Island stream six- to seven-fold, the benefits were offset by the natural carrying capacity limitations of the stream over winter. Other species such as chum and pink salmon enter the ocean as fry with little or no freshwater rearing, and improvements to spawning habitat will be most beneficial (Canada Dep. Fish. and Oceans and B.C. Min. Environ. 1980).

In this review, potential rehabilitation techniques have been separated into two categories: 1) those designed to rehabilitate spawning habitat; and 2) those for juvenile rearing habitat rehabilitation. In some cases, the same technique can be valuable for both spawning and rearing habitat restoration.

Spawning Habitat

Spawning habitat rehabilitation includes the following options: 1) gravel cleaning; 2) spawning gravel placement and catchment; 3) the provision of access for adult spawners above barriers; 4) side channel development; and 5) the use of incubation boxes.

Gravel cleaning

During the past 15 years a variety of efforts have been undertaken in the Pacific Northwest to remove sediments accumulated in spawning gravels. These include techniques to dislodge fine sediment from gravels, such as bulldozers and fire pumps, or more elaborate systems involving large tracked vehicles with vibrating buckets or hydraulic jets.

Bulldozers and gradalls:

Gravel cleaning by bulldozer is generally performed at high discharges when eggs and alevins are not present. At the Meadow Creek Kokanee Spawning Channel on Kootenay Lake, scarification of the channel is usually done in early August, prior to the annual spawning run. Efforts are limited to downstream sites in a watershed to avoid further degradation of spawning gravels below the area of cleaning. The use of heavy equipment precludes these kinds of operations in small streams with abundant accumulations of large organic debris, typical of streams on the Queen Charlotte Islands. As well, rehabilitating spawning habitat with a bulldozer has been successful only after the source of fine sediments has been stabilized or eliminated (Reeves and Roelofs 1982).

The Washington State Department of Fisheries (WSDF) has undertaken a number of gravel cleaning programs with the use of a bulldozer. Included among the areas cleaned was one downstream of a landslide on the Dungeness River (Heiser 1972) and some on the Cedar and Stillaquamish Rivers. Dick Allen (WSDF, personal communication) indicates that although these operations were undertaken without adequate design for subsequent evaluation, the streams appeared to return to a degraded condition within a single storm event. The WSDF no longer uses bulldozers to clean gravel. In British Columbia, bulldozers have been used to clean spawning gravel in specific situations such as in the Meadow Creek spawning channel (C. Wightman, B.C. Fish and Wildife Branch [BCFW], personal communication) and in the Qualicum River (a controlled-flow system).

A gradall with a 2.1-m wide bucket modified by the addition of a vibrator and a screened bottom has been used to clean gravel in the Nadina River, a sockeye spawning river in northwest British Columbia (Andrew 1981). Gravel is dug from the streambed with this bucket, which is then dipped in and out of the water while being vibrated, causing the fines to drop through the screen and into the hole in the streambed. The cleaned material is then spread on top in a layer

approximately 30 cm deep. Although the Nadina is lake-headed and carries a relatively small sediment load, cleaned gravel was gradually recontaminated with fines. The International Pacific Salmon Commission (IPSC) is no longer conducting gravel cleaning operations in rivers due to the short-term benefits derived from cleaning and the downstream adverse effects of sediment (F. Andrew, IPSC, personal communication). However, in an emergency where upslope siltation had been controlled, the gradall with a mounted vibrating bucket could be a feasible gravel cleaning technique.

Manual techniques:

Manual techniques, such as the use of fire pumps and hoses, are restricted to localized sites and generally must be sustained on a regular basis. For example, a 100-m section of spawning gravel at the outlet of Ruby Lake on the Sechelt Peninsula in British Columbia is cleaned annually with fire pumps and rakes (C. Wightman, BCFW, personal communication). Gabions designed to collect spawning gravels, such as on a tributary of the Trinity River in northern California, are cleaned at higher flows with fire pumps (K. Overton, U.S. Forest Service [USFS], personal communication).

Hydraulic jets:

A self-propelled amphibious vehicle for cleaning fine sediment from gravels was developed in Alaska and California in the 1960's (Meehan 1971). The "Riffle Sifter" was abandoned due to operational problems, but the concept of a hydraulic gravel cleaner has been revived in the State of Washington (Mih 1981). This machine uses high velocity water jets to dislodge sediments. The silt-laden water was collected by a suction system and discharged on the streambank.

Test results indicate that despite some promise, the gravel cleaning machine has considerable limitations (Allen et al. 1981). The machine is not effective in non-uniform substrates, shallow riffles, or in systems with abundant organic material that has to be

removed beforehand to allow the machine to operate in the stream. Gravel sampling in Kennedy Creek, Washington, indicated that the level of fines returned to pre-cleaning levels within one month, due to a recruitment of fines from upstream areas. Test results were more successful on Clear Creek which had ideal conditions of flow control and uniform substrate size. Dick Allen (WSDF, personal communication) indicates that in the future the gravel cleaning machine will be used for cleaning spawning channels and side channels that are being developed with controlled-flow inlets. He suggests that small "flashy" watersheds with unstable upslope areas are totally unsuited for a gravel cleaning machine.

For the past 10 years, the IPSC has successfully been using a machine for cleaning six spawning channels in the Fraser River drainage. This machine injects an air water mixture through pipes inserted 20 cm into the substrate (Andrew 1981). It is only suited for use in spawning channels, as it encounters difficulties in negotiating tight corners and cannot operate if there are any stones larger than 10 cm in diameter, or if a substantial amount of organic material is present. The cleaning operations are conducted when flows are sufficient to carry the silt-laden water out of the spawning channel.

In summary, a variety of experimentation with different gravel cleaning techniques in the Pacific Northwest appears to have arrived at a common consensus that gravel cleaning is only useful in specific situations. Experience has shown that gravel cleaning operations are most suited for stable systems such as lake-headed tributaries or locations where some degree of flow control has been achieved such as in spawning channels. In situations where the source of sediment is not controlled, the benefits of gravel cleaning are quickly negated.

The gravel cleaning techniques discussed do not appear to be appropriate for use in typical Queen Charlotte Island streams that have been damaged by mass wasting. Sediment inputs continue to occur

after the landslide event, and experience from efforts elsewhere suggests that any benefits from mechanical gravel cleaning would be short-lived.

Upslope stability programs:

In stream systems with excessive accumulations of sediments, the most effective rehabilitation measures will likely be those that attempt to stabilize the upslope areas. It makes little sense to conduct extensive cleaning efforts in the run-out and accumulation zone, if excessive amounts of material are still entering the stream from upslope areas.

The effectiveness of concentrating on watershed rehabilitation has been demonstrated on the South Fork Salmon River in Idaho (Platts and Megahan 1975). Road building and landslide activity in this watershed increased the river bedload to the point that mainstream spawning areas were choked with fines. A moratorium on logging and a watershed rehabilitation program has resulted in a progressive decline in sediments in spawning gravels, to the point that logging activities have been allowed to resume.

A second example of efforts to control sediments before they enter the stream has been undertaken on Horse Linto Creek, a tributary of the Trinity River in northern California. A landslide on this system resulted in silt and sand accumulations two to three times the pre-slide levels, and the spawning gravels have become imbedded with fines (G. Barnes, USFS, personal communication). In 1981, the U.S. Forest Service spent $200 000 to stabilize the toe of this landslide, to stop the flow of fines from contaminating the substrate. These measures are costly, but should be effective and long-lasting.

Probably the most extensive watershed rehabilitation program in North America is presently under way in Redwood Creek, California. Approximately $30 million is being spent in efforts to stabilize sediment sources in this watershed. The program has successfully

reduced erosion from logging roads and landings, but has been unable to successfully rehabilitate debris slides and avalanches and stored channel sediments (Kelsey et al. 1981).

Gravel placement and catchment

In situations where spawning gravels are limited, attempts have been made to add additional gravel or to stabilize existing gravel with in-stream structures. Most of these attempts on West Coast streams have been unsuccessful (Hall and Baker 1982), but continued efforts and design modifications are resulting in greater success.

Gravel addition:

Addition of spawning gravel to a natural, uncontrolled stream is usually not successful (Canada Dep. Fish. and Oceans and B.C. Min. Environ. 1980). Unless prevented from moving downstream, added gravel will often be deposited in pools and around rocks and log jams, to the detriment of salmonid rearing habitat. In a typical small stream with a maximum width of 10-14 m, slopes in excess of 0.3% produce velocities that during freshets will readily move spawning gravel (Canada Dep. Fish. and Oceans and B.C. Min. Environ. 1980).

Successful projects involving gravel placement have generally taken place in areas with stable flows and dense spawning populations. Examples of useful additions of gravel to spawning areas include the Lardeau River at the outlet of Trout Lake (Parkinson and Slaney 1975), and the outlets of Ruby and Chilliwack Lakes (C. Wightman, BCFW, personal communication).

Most streams affected by mass wasting on the Queen Charlotte Islands are not gravel deficient unless they have either been scoured by a debris torrent or unless debris accumulations prevented adequate gravel recruitment downstream. Gravel stability is generally a greater concern, and techniques designed to stabilize existing spawning gravels may be useful in some streams where natural

in-stream stabilizing features, such as large organic debris, are missing. Other techniques which have been used elsewhere are gabions, log sills, and rock weirs.

Gabions:

Gabions (rectangular wire-mesh baskets filled with rock) have been commonly used in the Pacific Northwest in attempts to hold spawning gravel in place. Hall and Baker (1982) conducted an extensive review of gabion installations in Oregon and Washington streams, and concluded that the majority of attempts to install gabions in streams have been unsuccessful due to structural instability or the failure of gabions to retain adequate-sized spawning gravels.

There have been recent improvements in gabion designs, which suggest they can be a useful technique for collecting and stabilizing spawning gravels (Reeves and Roelofs 1982). One modificaton that has improved the stability of structures is the use of V-shaped structures rather than the more conventional method in which gabions were placed perpendicular to the stream. A V-shaped gabion set at 30^{o} to the bank will spread the water over double the distance of a conventional structure, and will reduce scour below the gabion (Anderson 1981).

The ends of gabions are toed 1-1.5 m into the banks and rip-rapped to prevent flows from washing around the ends. Sections are cabled together, and the entire structure is cabled to large trees or rocks near the banks. Anderson and Cameron (1980) estimate that 90% of the gabion structures installed in the Coos Bay District in Oregon have remained reasonably stable. Construction costs for 38 structures completed in 1981 ranged from $12-17 per lineal foot and $500-2000 per structure (Anderson 1981).

Another recent improvement in gabion design has been the use of perforated pipes in the base of gabions. The movement of sands and silts through holes in the pipes helps maintain cleaner gravels

behind the gabions (K. Overton, USFS, personal communication). Perforated 10-cm diameter pipes placed in the gravel at 1-m intervals are being used by the U.S. Forest Service in northern California. This "passive cleaning" modification may be particularly applicable to streams downstream of landslide areas which are subject to the deposition of fines from upstream sites.

Log sills:

Log sills are an alternative to gabions for use as stabilizers of spawning gravels in systems where log material is readily available. Although log sills have been used in a variety of streams in the Pacific Northwest for the past 20 years, little information on their relative success as been documented.

Bender (1978) reports that five log sills placed in Anvil Creek, Oregon, successfully held spawning gravel that was subsequently used by chinook salmon. Submerged logs have been used to stabilize spawning gravels at the outlet of Ruby Lake (Canada Dep. Fish. and Oceans and B.C. Min. Environ. 1980).

A rehabilitation program on Clear and Granite creeks in Oregon is making extensive use of log sills to stabilize gravels and develop pool habitat (Andrews 1981). Over 100 log weirs, at a cost of approximately $900 each weir, are planned for these two creeks. Anderson (1981) reports that the construction costs of 16 log sills ranged from $400-900 per structure. The logs, keyed into the bank up to 5 m, are lined with a filter fabric to prevent undercutting.

Log sill structures installed in the Medford, Oregon, area have remained intact after 8 years and despite a severe storm (B. Besey, Bureau of Land Management [BLM], personal communication). The WSDF started using log sills in the late 1960's, changed to gabion construction, but are now returning to log sills (D. Allen, WSDF, personal communication). They are less expensive and are expected to last as long as gabion structures.

Gabions offer the advantage of being light-weight, portable, and possess more give than the log structures. As well, gabions and rock weirs are not watertight. This promotes a good exchange of flow between the stream and the gravel spawning bed for a considerable distance upstream of the structure (Canada Dep. Fish. and Oceans and B.C. Min. Environ. 1980). On the other hand, large wood material for log sills is abundant and readily available on many streams in the Queen Charlotte Islands.

Both techniques have promise as methods of stabilizing and collecting spawning gravels in small Queen Charlotte Islands streams that have historically had good fish runs but may be lacking stable spawning gravels.

Improved spawner access

A third approach to spawning habitat rehabilitation in the Queen Charlotte Islands is the provision of access for adult spawners above log jam barriers. Hall and Baker (1982) report that despite extensive log jam removal programs throughout the Pacific Northwest, few efforts have been made to evaluate the effects of log jam removal. They estimate that during the past 45 years, approximately 1000 debris accumulations have been removed on one river in Oregon alone.

Baker (1979) points out that a careful analysis should be made, weighing the short-term impacts of sediment and debris releases on downstream rearing and spawning habitat against the increased use by anadromous fish above debris jams. As an example, Brown (1975) estimates that 300-500 m^3 of material is typically stored behind a 3-5 m high log jam, and Beschta (1979) indicated the removal of a large log jam in coastal Oregon resulted in the release of 5000 m^3 of sediment. On the positive side, a log jam removed on Haslam Creek near Nanaimo resulted in improved adult access to an additional 13 km of stream (Narver 1971).

Many of the debris accumulations associated with debris torrents on the Queen Charlotte Islands are formed near the upper extent of anadromous fish habitat, and only small gains to additional spawning areas may be made with the removal of jams. A more important consideration might be whether or not these jams are interrupting the flow of gravels to downstream spawning areas. Consideration should be given to the partial removal of the jam around the side, to allow for continued movement of bed materials without enormous releases of sediment, and to allow for fish passage when it is determined that significant habitat exists above the barrier. It should be recognized however, that this could lead to some bank erosion if the thalweg of the stream relocates to this opening.

Log jam removal has been undertaken on the Queen Charlotte Islands, often because the logs threaten bridges. For example, debris accumulations from torrents have been removed on Sachs Creek and South Bay Dump Creek (K. Moore, BCFW, personal communication). Opportunities also exist to improve access to upstream areas by removing natural log or rock barriers. For example, extending suitable access for coho, steelhead, and pink salmon into upper Gate Creek, Lyell Island, might result in far greater benefits to the fishery resource compared to equivalent stream restoration efforts in Sandy Creek or Richardson Creek, two streams on the same island which have been subject to extensive mass wasting events in the past.

Methods of log jam removal depend on access and equipment available. A grapple yarder was used to remove a log jam on Sachs Creek at a cost of approximately $2000. In some situations it may be possible to burn or salvage wood in a jam and to remove materials from behind a jam (Canada Dep. Fish. and Oceans and B.C. Min. Environ. 1980). Any restoration work should be conducted as soon after the event as possible (in the case of debris accumulations associated with torrents) so that the stream recovery will be uninterrupted by subsequent stream rehabilitation activities, and so that merchantable wood may be recovered to help offset costs.

Side channel development

An alternative to rehabilitation of spawning gravels in the main channel of a stream is the development of side channel spawning particularly for pink, chum, and coho salmon. Under most situations side channels provide a more stable flow and temperature regime than the main channel, and production is usually limited by inadequate water during certain periods. Efforts to concentrate seepages and subsurface flows to provide adequate spawning and incubation flows can be complemented with a variety of channel improvement efforts, such as establishing gradient controls with gabions, improving spawning gravels, and constructing pools for holding fish (Canada Dep. Fish. and Oceans and B.C. Min. Environ. 1980).

Chum salmon spawning areas have been developed in a number of groundwater-fed side channels in southwestern British Columbia (Lister et al. 1980). Egg-to-fry survival in these areas was approximately double the average recorded at natural spawning locations in the province. The development of a side channel spawning area for chum salmon has been initiated on the Satsop River in Washington (D. Allen, WSDF, personal communication). This channel has been dyked, water levels are controlled at a culvert inlet, and a series of gabions have been installed to hold gravel in place.

The development of stable side channel spawning areas in some streams on the Queen Charlotte Islands may serve as a compensatory measure in lieu of spawning area rehabilitation of those small streams directly affected by mass wasting, but which themselves are poor candidates for gravel rehabilitation due to unstable upslope areas. Even side channels could be affected by high levels of suspended sediment resulting from upslope failures.

Incubation boxes

Stream-side incubation boxes can be used in conjunction with rehabilitation projects to ensure that stocks are maintained and that stream production is rapidly brought to its potential in areas where

spawning gravel restoration has occurred. In Washington State, incubation boxes are also used to partially mitigate salmonid production losses due to land-use activities (Bauersfeld et al. 1981).

On the Queen Charlotte Islands incubation boxes have been used with some success in Sachs and Hans creeks on Moresby Island, and in Thorsen Creek, Sewell Inlet. As experience is gained and stable water supplies identified, this program should improve and incubation boxes may offer a limited substitute spawning environment to at least maintain stocks in streams where spawning gravels have deteriorated as a result of mass wasting. The cost of installation and maintenance of the two boxes on Hans and Sachs creeks was $20 000 during the first year and should be less during subsequent years (B. Pollard, MacMillan Bloedel Ltd., personal communication).

Before outplanting fry from an incubation box into a debris torrented stream, an assessment of the total available habitat in that stream should be made.

Rearing Habitat

There are a number of techniques suitable for juvenile coho and steelhead rearing habitat rehabilitation. These include the placement of in-stream structures to improve habitat diversity and increase cover for juvenile fish, side channel development, and the enhancement of backwaters and groundwater-fed pond areas. Techniques such as flow augmentation, semi-natural rearing channels, and stream enrichment are not discussed in this report since they are not considered realistic options for use in the types of streams that are damaged by mass wasting in the Queen Charlotte Islands.

In-stream structures

In-stream structures to enhance trout populations have been used extensively in the mid-eastern United States. The most detailed and comprehensive evaluation of trout habitat development has been carried out in Lawrence Creek, Wisconsin (Hunt 1976). The use of

in-stream structures to increase pools and overhead cover resulted in substantial increases in the older age classes of brook trout. White and Brynildson (1967) have reviewed many of the techniques suitable for use in small, meandering streams with moderate flow regimes. The application of these techniques to West Coast streams is probably limited to the more stable lake-outlet systems.

A number of in-stream structures for rearing habitat improvement have shown promise for Pacific Northwest streams. Boulder clusters, log placements, gabions, and the development of pools by blasting in bedrock streams are presently used to improve rearing habitat.

Boulder placement:

The use of boulders to increase rearing habitat for juvenile coho and steelhead is probably the most effective technique in most British Columbia streams (Canada Dep. Fish. and Oceans and B.C. Min. Environ. 1980). A detailed study of different configurations of boulder placement was conducted in the Keogh River on northern Vancouver Island (Ward and Slaney 1979). Boulders arranged in clusters of up to seven were an effective means of improving steelhead parr and coho fingerling rearing habitat in a section of river that had previously been logged and had much of its in-stream cover removed by a stream clearance program. Boulders of approximately 60-100 cm in diameter proved to be the best for both stability and scour effect. Boulder V-notched weirs, and boulder deflectors with log cover were found to be less stable and had lower densities of fish use than the clusters. Attaching log cover to boulder clusters resulted in slightly higher fish densities (Ward and Slaney 1979). The use of a helicopter to place boulders compared favourably with the costs of using heavy equipment.

Boulder placements in Red Cap Creek, California, increased the steelhead parr population three-fold over control sections (Brock 1982). Some boulders were buried in deposited bedload during a

winter freshet. More severe problems were encountered on the Salmon River, Vancouver Island, where boulder placements were ineffective due to too much bedload being deposited around the boulders. At least four other streams in southwestern British Columbia have recently had boulders added to improve trout and coho rearing habitat (C. Wightman, BCFW, personal communication). As well, a small program of boulder placements is presently being undertaken on Brent Creek in the Queen Charlotte Islands (B. Pollard, MacMillan Bloedel Ltd., personal communication).

Boulder placement in clusters could be a useful technique for improving rearing habitat on some Queen Charlotte Island streams, particularly in small steelhead systems that lack overwinter cover for parr. As with most stream rehabilitation methods, this technique is most suited for stable, lake-headed systems, and boulder placement elsewhere will result in a high possibility of structure failure.

Log sills and gabions:

Log sills and gabions were discussed previously as a means of stabilizing spawning gravels. The plunge pool formed below the gabion or log sill may also provide juvenile rearing habitat (Anderson and Cameron 1980; Andrews 1981). In many of our small coastal streams, the availability of pool habitat during lowest flows may limit the stream's rearing capacity, particularly for older age classes of juvenile steelhead and coho. The addition of pool habitat could increase the rearing capacity of these streams.

Gabions installed in the Keogh River did not increase the abundance of steelhead parr (Ward and Slaney 1979). They provided little habitat diversity and were structurally unsound compared to boulder structures. The gabions did provide some winter cover for steelhead, and it was noted that they may be useful in some small coho nursery streams, particularly if combined with boulder placements.

Blasting pools:

The importance of pool habitat to juvenile rearing has stimulated efforts to create new pools in streams lacking pool habitat. For example, a program of blasting and excavating pools in the bedrock substrate of Vincent Creek, Oregon (80% riffle and 20% pool habitat at low flows) resulted in a significant increase in the abundance of juvenile coho salmon (Anderson and Miyajima 1975). Several other programs involving pool blasting in Oregon streams have met with mixed success (Hall and Baker 1982). Developing pool habitat in bedrock streams is also a continuing stream improvement program in Alaska (Sweet 1975). Reported costs for pool blasting range from $200-400 per pool (Sweet 1975; Anderson 1981).

Blasting bedrock pools may have potential for improving coho rearing habitat on some Queen Charlotte Island streams that possess bedrock substrate and lack pool habitat. However, new pools would have to be designed to ensure they did not completely fill with bedload, and continued to offer suitable habitat during freshets.

Other in-stream techniques:

A number of other in-stream techniques aimed at providing cover for juvenile salmonids in streams deficient in natural cover may have merit. For example, trees can be attached to the streambank and to instream boulders, or root wads can be anchored at key locations to provide cover (Canada Dep. Fish. and Oceans and B.C. Min. Environ. 1980). Root wad structures have been installed in Colquitz Creek near Victoria to provide cover for coho and cutthroat trout in this small urban stream.

These techniques are essentially untested in the Pacific Northwest, but have the advantage of using natural materials readily available. However, their potential for creating debris accumulations in small streams and their relatively short life-span may limit their application.

Side channel and pond development:

Side channel areas typically offer more stable rearing conditions than main channel sites. Efforts to concentrate seepages and provide stable flows in side channels can be complemented with a variety of in-stream structure developments to improve rearing habitat (Canada Dep. Fish. and Oceans and B.C. Min. Environ. 1980). This approach could help to compensate for habitat degradation in main channel sites, where rehabilitation efforts may be short-term due to extreme flows and high bedload movement.

Intermittent flood channels and groundwater-fed pond areas adjacent to streams provide important overwintering habitat for juvenile coho (Bustard and Narver 1975; Peterson 1980). Improvement of these areas by developing access and concentrating flows may be a useful technique to increase a stream's capability to produce coho smolts. It might also prove less labour-intensive than using in-stream structures.

CONCLUSION

A variety of available techniques offer some potential means of rehabilitating Queen Charlotte Islands streams affected by mass wasting. In this review it was assumed that potential impacts to spawning fish would include a deterioration of spawning gravel quality and stablity, and a loss of upstream access to former spawning areas.

After considerable experimentation with gravel cleaning techniques in the Pacific Northwest, there is a common consensus that gravel cleaning is unsuitable for use in the small, high-energy streams typically subjected to landslides in the Queen Charlotte Islands. A program of watershed stabilization to reduce sediment inputs to stream systems, in addition to temporary measures such as incubation box facilities to ensure the maintenance of spawning stock, may be the only effective means of dealing with deteriorated gravel quality in spawning areas. Gabion and log sill structures offer a means of improving spawning gravel stability in areas where natural

stabilizing features have been lost. Recent improvements in structure design, including V-shapes and perforated pipes for passive cleaning of fines, should improve the success rate of these in-stream structures. As well, the development of stable side channel areas for spawners holds promise as a means of spawning stock rehabilitation in situations where suitable sites can be identified.

Mass wasting events may also adversely affect the rearing habitat of juvenile salmonids as a result of the redistribution of large organic debris and of changes in channel characteristics that result in less pool habitat and more subsurface flows. A variety of techniques have promise as means of rehabilitating rearing areas, ranging from the development of in-stream structures such as boulder placements, log sills, and gabions to improve habitat diversity and the amount of pool area; to off-channel developments such as side channel and pond rearing areas. Each of these techniques centres on different life history stages of salmonids, and requires a thorough understanding of the factors limiting production before they can be effectively undertaken. Techniques that focus on areas adjacent to, rather than in the main channel itself, will probably be most durable and effective.

In conclusion it is important to point out that it is more economical to prevent initial habitat degradation than to repair it, and some damage is not reversible (Narver 1973; Hall and Baker 1982). Resource managers must be cautioned that, at the planning and execution stage of forestry operations, stream rehabilitation is not a reasonable alternative to sound habitat protection measures.

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APPENDIX

PROPOSED 1982 PILOT REHABILITATION STUDIES

The following outline for potential stream rehabilitation studies which can be implemented by the FISH/FORESTRY INTERACTION PROGRAM in 1982 has been prepared without the benefit of results from ongoing impact studies. Accordingly, this stage of the program should be kept small and flexible until such results can be incorporated into the design. Preliminary rehabilitation studies initiated in 1982 could serve as a test program for techniques which may be applied on a larger scale at a later date.

Based on information derived elsewhere, it is assumed that downstream of mass wasting, spawning gravels in streams less than 2 percent gradient are accumulating coarser particles, not readily flushed out during freshets. It is also assumed that gravels in spawning areas have become less stable as a result of redistribution of large organic matter and the accumulation of excessive bedload material. These factors probably result in poorer survival of salmonids, particularly pink and chum salmon. For this reason, it is recommended that a major emphasis of stream rehabilitation should focus on the provision of a stable spawning environment with clean gravels for pink and chum salmon egg and alevin development.

The most fruitful approach for long-term improvement of stream conditions is to stabilize upslope sites which are contributing to in-stream problems. It is recommended that any in-stream rehabilitation program should work in close conjunction with upslope watershed stabilization efforts.

Sachs Creek, with its history of logging-related mass wasting problems, is a good candidate watershed to conduct pilot studies of several stream rehabilitation techniques. It has historically had good escapements of pink salmon (annual average 2,500 fish). As well, Sachs Creek has a run of chum and coho salmon, steelhead and cutthroat trout (Salmo clarki) and Dolly Varden char (Salvelinus malma). There is good access to the lower 2 km of Sachs Creek, the main spawning and rearing area for anadromous fish. Furthermore, MacMillan Bloedel Ltd. is interested in a joint rehabilitation program in this watershed. An existing incubation box program for pink and coho salmon on

this stream should assist continued spawner recruitment despite apparent deteriorated conditions in the spawning gravels following a major debris torrent in upper Sachs Creek in October 1974.

A pilot rehabilitation study on Sachs Creek could involve the following projects:

1) A series of gabions and log sills could be established in the lower 2 km of Sachs Creek to stabilize spawning areas. Long riffles could be separated to create pool-riffle complexes which would improve the stability of spawning gravels and diversify rearing habitat. Perforated pipes installed into the gabion structures to improve gravel quality by "passive" movement of fines is the most promising technique to improve spawning gravel quality. A series of 10 log sills and 10 gabion structures in pairs to compare effectiveness and durability of the two techniques would cost approximately $40,000 based on experience elsewhere.

2) A study of rearing habitat development aimed primarily at improving juvenile coho overwintering habitat in side channels and ponds could be undertaken on Sachs Creek. A potential side channel development site is located 1500 m upstream on Sachs Creek. Possible options for this site include the development of channels and pools on the flats between the main and side channels, a control structure at the top end of the channel to modify winter freshets and ensure adequate flows during low summer periods, and the placement of log structures for diversity and cover.

   A small pond located at approximately 1900 m on Sachs Creek may be suited for coho rearing. The development of access into this pond from Sachs Creek or stocking it using coho fry produced in the incubation box could be tested to enhance the coho rearing potential of Sachs Creek.

   Cost estimates for these developments would be dependent on further field evaluations including preliminary engineering work assessing the suitability of these sites for detailed work. Additional cost allowances for any in-stream rehabilitation projects

should include the cost of maintenance of structures on an annual basis (est. 10%) and contract administration costs. As well, programs designed to evaluate the effectiveness of in-stream works would be required. For example, the rearing projects would require detailed assessments of juvenile salmonid production pre- and post-development, including the possible use of trapping devices to determine smolt output from the side channel and pond area.

Other stream rehabilitation projects which might be undertaken include the following:

1) Partial log jam removal programs on debris torrented creeks which no longer have adequate gravel recruitment. For example, the removal of part of the log jam on Showmar Creek (tributary of the Deena River) and on a tributary of Mosquito Lake may benefit downstream areas which are deficient of spawning gravels.
2) Pond and side channel developments in other systems for both rearing and spawning habitat hold promise. This program would depend on field crews identifying suitable sites during the course of stream surveys. The Deena River may offer a number of opportunities for such developments.
3) A program to re-establish stream control structures to collect and stabilize gravels in MacMillan Creek has a high probability of failure due to upslope instability, a high gradient channel (3.5% slope in lower reach) and historically poor recruitments of fish. It does have the benefit of easy access and large woody material readily available. It is improbable that the benefits to the fisheries resource from rehabilitation works in a stream with the characteristics of MacMillan Creek could ever be cost-effective.